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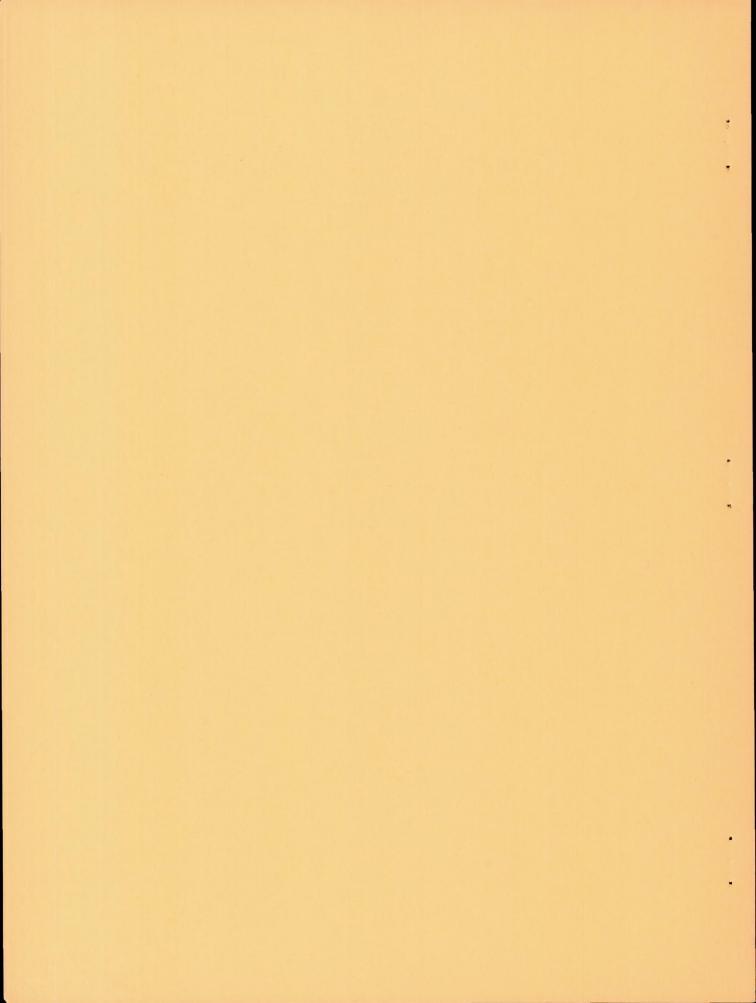
PROPELLER-NOISE CHARTS FOR TRANSPORT AIRPLANES

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SUMMARY

Calculations of rotational-noise and vortex-noise levels at a distance of 300 feet for engine ratings of 1,000 to 10,000 horsepower have been made for a large number of propellers in static operation. Propellers with three, four, six, and eight blades and diameters of 8, 12, 16, and 20 feet are considered. The results are presented in chart and table form for rapid estimation of the noise levels and spectrums in the range of tip Mach numbers from 0.40 to 1.00. Applications of the data to tandem and dual-rotating configurations are given and the supersonic-type propeller is also briefly considered.

It is emphasized that, if noise reductions are to be obtained or if present noise levels are to be maintained for higher power ratings, future propeller designs should operate at lower tip Mach numbers than are currently being used. Single- rather than dual-rotating propellers were found to generate the lowest over-all noise levels for a given number of blades.

INTRODUCTION

The principal neighborhood nuisance factor in connection with airports is the noise resulting from ground and flight operations of aircraft. The external-noise problems are currently overshadowing the ever-present problem of proper protection for the passengers and crew. Reference l indicates that increasing engine power ratings, greater traffic densities, and greater concentrations of population near airports are combining to intensify the airport noise problem.

Although the possibility is recognized that the operation of jet engines may eventually create another very serious transport-airplane noise problem, the propeller is currently one of the major sources of external noise. As engine power ratings increase, propeller noise levels, in general, will also increase unless a concerted effort is made in the interest of noise reduction. For future propeller aircraft, the adherence to current design trends will probably not be feasible if noise reductions are to be obtained or even if present levels are to be maintained.

References 2 and 3 deal with the noise and performance, respectively, of propellers of personal-owner airplanes. The present paper and reference 4, which cover approximately the same ranges of propeller parameters, are essentially extensions of the studies of references 2 and 3 to propellers of transport airplanes. Information in regard to noise levels is presented in the present paper to enable the designer to evaluate new configurations in the early design stage and to evaluate the benefits from possible modifications to existing configurations.

SYMBOLS

M_{t}	rotational tip Mach number
v _{0.7}	section velocity at the 0.7-radius station, fps
A	propeller-disk area, sq ft
A_{B}	propeller-blade area, sq ft
N	propeller rotational speed, rpm
S	distance from propeller to observer, ft
В	number of blades
T	thrust, 1b
P_{H}	power input to propeller, hp
D	propeller diameter, ft
I	sound-pressure level, db
Ī	over-all sound-pressure level, db
\overline{I}_{V}	sound-pressure level of vortex noise, db
$\overline{\mathtt{I}}_{\mathrm{R}}$	sound-pressure level of rotational noise (summation of first four harmonics), db
p	root-mean-square sound pressure of a given harmonic, dynes/sq cm
$J_{mB}(x)$	Bessel function of order mB and argument $x = 0.8 M_{t} mB \sin \theta$
β	angle between propeller axis of rotation and line from center of propeller to observer (ranges from 0° in front of propeller to 180° behind it), deg

$^{\mathrm{C}}_{\mathrm{P}}$	power coefficient, $550P_{\rm H}/\rho\left(\frac{N}{60}\right)^3D^5$
C_{T}	thrust coefficient, $T/\rho \left(\frac{N}{60}\right)^2 D^{14}$
${\tt C}_{\tt L}$	effective lift coefficient, as defined in appendix C, $2T/\rho A_B V_{0.7}^2$
С	sound speed, fps
k, k'	constants of proportionality
m	order of harmonic
ρ	air density, slugs/cu ft
f	frequency, cps
Subscripts:	

ESTIMATION OF PROPELLER NOISE

1, 2, 3, 4 number of the harmonic

General Considerations

Most external-noise problems result from static operation of aircraft or from take-off and landing operations. The aircraft in these operations is relatively close to the observer and, in the take-off condition particularly, is using maximum power. For the purposes of the present paper, the noise for various transport propeller configurations has been calculated for static conditions. These results may also be assumed to apply approximately to conditions of low forward speed as in take-off and landing.

Noise from propellers consists of a rotational component and a vortex component. The rotational component is due to the steady aerodynamic forces on the propeller blade, whereas the vortex component results from the shedding of vortices from the propeller blade. Since the laws of generation of these two components are different, they may vary in importance as the operating conditions of the propeller change and also as the configuration changes. These effects are illustrated qualitatively in figure 1, which also indicates the nature of these two noise components. Figure 1(a) is a noise spectrum of a propeller operating near a tip Mach

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number of 1.0. For this condition, the major contribution is from the rotational component. The spectrum consists of several discrete frequencies which are harmonically related to the blade passage frequency and are of constant amplitude.

Figure 1(b) is the vortex-noise spectrum from a rotating circular rod and illustrates the nature of vortex noise from propellers. This noise is random and has a continuous spectrum over a range of frequencies determined by the section velocity and geometry. The frequencies are associated with the Kármán vortex street in the wake and may be predicted by the Strouhal relation as given in reference 5. The maximum intensity in figure 1(b) corresponds to the Strouhal frequency in the wake of the blade at its half-radius section. In the case of a propeller, the vortex-noise spectrum will usually be broader than that of figure 1(b) because of the variation in blade thickness along the span.

For the case in which a propeller operates at a low rotational speed, the rotational and vortex components may be of the same order of magnitude; if they are, the type of spectrum shown in figure 1(c) results. In general, the vortex component has a higher frequency content than the rotational component and increases in intensity at a slower rate as a function of tip speed. As a result, high- and low-tip-speed propellers will have quite different noise spectrums. The vortex component is assumed to be most intense on the axis of rotation in front of and behind the propeller plane ($\beta = 0^{\circ}$ and $\beta = 180^{\circ}$), whereas the rotational component is usually a maximum at values of azimuth angle β between 90° and 120° .

Charts and Tables

Calculations of propeller rotational- and vortex-noise levels have been made by the methods outlined in appendixes A and B and in accordance with the simplifying aerodynamic assumptions of appendix C. Intensities and frequencies of the first four rotational harmonics, as calculated for a distance of 300 feet by the method of Gutin (ref. 6) in appendix A, are listed in table I for a wide range of propeller parameters. Figures 2 to 7 give the rotational- and vortex-noise levels as functions of tip Mach number for propellers of three, four, six, and eight blades and for engine ratings of 1,000, 2,000, 4,000, 6,000, 8,000, and 10,000 horse-power. The rotational-noise values, plotted as the solid-line curves in these figures, were obtained by a summation of the noise from the first four rotational harmonics as listed in table I. In order to estimate the noise levels for two and four propellers in random phase, the values given in figures 2 to 7 should be increased by 3 and 6 decibels, respectively.

Vortex-noise levels, presented in figures 2 to 7 as the dashed lines, were estimated by means of the method outlined in appendix B, which is based on reference 7. The vortex-noise levels for a given propeller are

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higher for the stalled condition than for the unstalled condition. The levels of figures 2 to 7 are calculated for the unstalled condition and hence may be as much as 10 decibels too low for some operating conditions.

Single-rotating propellers. The data presented in table I and in figures 2 to 7 are directly applicable to single-rotating propellers. A special type of single-rotating propeller is the tandem configuration which consists of two stages of blades having the same thrust axis and direction of rotation. On the basis of the results of reference 6, the noise field from this configuration is believed to be approximately the same as for a conventional single-rotating propeller with the same number of blades and with the same angular blade spacing.

Dual-rotating propellers .- The data of figures 2 to 7 may also be used to estimate the noise from dual configurations with the aid of figure 8. The noise from a dual-rotating propeller may be determined from the noise fields of both of its component propellers (ref. 8). Figure 8 has been prepared to illustrate the manner in which these noise fields add up. The noise from a propeller has been shown to be independent of its direction of rotation and hence, in the dual-rotating case, the instantaneous phasing of the blades determines the nature of the sound field generated. This phenomenon is illustrated in figure 8, in which the radiation pattern is shown by the solid line for a four-blade dualrotating propeller and by the dashed lines for a two-blade single- and a four-blade single-rotating propeller. The two stages of blades of the dual-rotating propeller are geared so that the blades overlap on axes AA' and BB' and are equally spaced along axes CC' and DD'. The sound intensity is a maximum on the overlap axes where the propeller appears to the observer as a two-blade propeller and is a minimum on the axes where it appears as a four-blade propeller. In addition to the change in overall levels as a function of the observer's position, the spectrums also change. On axes AA' and BB' the spectrums have all the harmonics of a two-blade propeller, whereas on axes CC' and DD' the spectrums have only the frequencies of a four-blade propeller.

The intensity variations as a function of the observer's position can be estimated for various dual configurations with a wide range of operating conditions from the data of figures 2 to 7. For example, it can be shown with the aid of figure 4(b) that the noise levels for a six-blade dual-rotating propeller absorbing 4,000 horsepower at a tip Mach number of 0.80 would vary from 111 to 116 decibels depending on the observer's position relative to the overlap axis. The maximum and minimum values correspond to those for a three-blade and a six-blade single-rotating propeller, respectively, at the same power loading as the dual configuration.

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Supersonic-type propellers. The over-all noise from a propeller operating at supersonic tip speeds may be estimated from the curves of figure 9, which have been prepared by extrapolating the measurements of reference 9 to greater distances and to higher powers. The tests of reference 9 indicated that the noise from this type of propeller was a maximum in the plane of rotation, that for a given power loading the noise was essentially independent of tip Mach number in the low supersonic range, and that only a small reduction in noise could be expected from an increased number of blades. Although figure 9 applies directly to a two-blade propeller at a tip Mach number of 1.20, the data of the figure may be interpreted as the maximum noise levels that would be encountered in the low supersonic range of tip speed for any propellers at the appropriate power loadings.

DISCUSSION OF RESULTS

Tip Mach Number

The variation of sound pressure as a function of tip Mach number at a constant power is shown in figures 2 to 7 for various propellers in the subsonic tip Mach number range. These figures show that a reduction in tip Mach number is always beneficial in reducing the noise and that the reductions occur at a faster rate for propellers with a larger number of blades. Since the vortex noise decreases at a slower rate with tip Mach number than the rotational noise, it may become relatively important at the low tip Mach numbers. In that range the propeller noise spectrum may contain a relatively high proportion of vortex noise.

Although the supersonic-type propeller offers certain weight and performance advantages, its use commercially may be greatly limited because of its high noise levels. If any effort is made in the interest of noise reduction, the trend would be toward lower tip speeds than are currently being used rather than toward higher ones.

Number of Blades

An increase in the number of blades is generally beneficial in reducing noise. This principle is well-established for conventional single-rotating propellers and is believed to be equally applicable for tandem configurations with uniform angular blade spacing. The variation of sound pressure as a function of number of blades at a constant power is given in figures 2 to 7 for various tip Mach numbers. In general, the largest noise reductions are obtained at the lower tip Mach numbers and relatively small reductions are obtained at the higher ones. In the tip Mach number range, where the vortex noise may be an appreciable part

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of the total, however, an increase in the number of blades may result in little or no over-all noise reduction.

Dual-rotating propellers have unique directional patterns which tend to minimize the benefits from an increased number of blades. Figure 8 shows, for example, that an eight-blade dual propeller has eight maximums and eight minimums in its radiation pattern. As the number of blades increases, the maximums and minimums are spaced closer together and hence it becomes more difficult to derive benefits from these directional effects. As a result of this nonuniform noise field, a small change in the orientation of the propeller with respect to the observer may cause a rather large change in the level of noise at the observer's position. The magnitude of this variation in noise level is a function of the propeller tip Mach number, and for a tip Mach number of 0.50 this variation would be of the order of 20 decibels for the conditions of figure 5(c). An observer inside the airplane would normally not be subjected to this intensity variation since the orientation of the propeller with respect to the airplane is fixed. This phenomenon would be especially annoying to observers on the ground during maneuvering flight at low altitudes.

Power Loading

The power loading of the propeller is a function of both the power input to the propeller and the propeller diameter; figure 10 shows that the noise generated is a function of both of these parameters. For any given propeller diameter the sound levels are seen to increase by approximately 5 to 6 decibels as the power is doubled. This finding is general and applies approximately to all tip speeds.

An apparent discrepancy arises when the power loading is changed by changing the diameter of a propeller. Figure 10 indicates, for instance, that a halving of the diameter for a given power increases the sound levels by 5 to 6 decibels, whereas a 10 to 12 decibel increase would be expected solely on the basis of a resultant quadrupling of the power loading. Two effects are involved one of which partially compensates for the other. A halving of the diameter effectively doubles the distance from the observer to the source and thus tends to neutralize the effect of increased power loading. For a given power input the use of as large a diameter as possible to reduce the power loading to a minimum is advantageous.

CONCLUDING REMARKS

Information with which to estimate the noise from propellers of transport airplanes for various operating conditions has been presented. It is emphasized that, if noise reductions are to be obtained or if present noise levels are to be maintained for higher power ratings, future propeller designs should operate at lower tip Mach numbers than are currently being used. Single- rather than dual-rotating propellers were found to generate the lowest over-all noise levels for a given number of blades.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., March 18, 1953.

APPENDIX A

CALCULATION OF ROTATIONAL NOISE

Rotational-noise values of the present paper have been calculated by the method of Gutin in reference 6, which has been confirmed by the experiments of reference 9. The Gutin equation in a form convenient for engineering use is as follows:

$$p = \frac{169.3 \text{mBDM}_t}{2 \text{sA}} \left[\frac{P_H}{c \left(0.8 \text{M}_t\right)^2} - T \cos \beta \right] J_{mB}(x)$$
 (1)

The sound pressure p corresponding to a given harmonic is thus seen to be a function of the power PH, tip Mach number Mt, number of blades B, propeller diameter D, propeller-disk area A, and azimuth angle of the observer β . For the purposes of this paper, β was assumed to be 105° since that value corresponds to the angle of maximum radiation for most of the propeller configurations considered. Calculations were made for a distance s of 300 feet, a sound speed c of 1,126 feet per second, and values of thrust T which were estimated by the method of appendix C.

Calculations of the sound pressure p for values of mB corresponding to the first four rotational harmonics have been made and converted to sound-pressure levels. These values are given in table I along with the corresponding frequencies for various combinations of propeller tip Mach number, number of blades, and power input. Summations have been made by taking the square root of the sum of the squares of the pressures of the first four harmonics and these results, after conversion to levels \overline{I}_R in decibels, are plotted as the solid-line curves in figures 2 to 7.

APPENDIX B

CALCULATION OF VORTEX NOISE

Vortex-noise levels were calculated by a method based on the work of Yudin in reference 7. For rotating rods having airfoil sections, as well as for those having circular cross sections, the vortex-noise energy was concluded to be proportional to the first power of the blade area and to the sixth power of the section velocity. Thus the following equation was used to calculate the vortex-noise levels in decibels for figures 2 to 7:

$$\overline{I}_{V} = 10 \log_{10} \frac{kA_{B}V_{0.7}^{6}}{10^{-16}}$$
 (2)

where k is the constant of proportionality evaluated tentatively as 3.8×10^{-27} in the work of reference 2.

A plot of the vortex-noise levels as a function of blade area for a range of tip Mach number is given in figure 11. Figure 11 is a summary of the vortex-noise levels plotted as the dashed curves of figures 2 to 7 and should be considered tentative pending further experimental confirmation.

APPENDIX C

ESTIMATION OF STATIC THRUST AND PROPELLER-BLADE AREA

In order to make calculations of the noise levels generated by various propeller configurations by means of equations (1) and (2), some of the interrelated aerodynamic and geometric parameters must be known. Some simplifying assumptions were made in order to expedite the calculation of static thrust and propeller-blade area. Although they are not considered adequate for aerodynamic studies, the resulting equations are considered satisfactory for the purposes of this paper.

Figure 12 gives C_P per unit horsepower as a function of tip Mach number for various propeller diameters. For any other power rating, C_P is easily obtained by multiplying the ordinate of figure 12 by the horsepower. For given values of C_P , D, and M_t the associated static thrust for use in equation (1) was determined from figure 13. The thrust calculations of figure 13 made use of the relation

$$C_{\rm T} = k' C_{\rm P}^{2/3}$$

where k' is a constant of proportionality evaluated as 0.75. This value was chosen on the basis of experimental results of reference 10 and appears to be valid for propellers operating near the stall.

From the expression for differential thrust given in reference 11, the following equation, which assumes that the lift is approximately equal to the thrust, may be derived:

$$A_{\rm B} = \frac{2T}{\rho c_{\rm L} v_{\rm 0.7}^2}$$

For the purposes of this paper it is assumed that $C_{\rm L}=0.4$, that $\rho=0.002378$ slugs per cubic foot, and that $V_{0.7}$ is the section velocity at the 0.7-radius station. This expression for blade area is evaluated for the ranges of static thrust and tip Mach number of the present studies for use in calculations of vortex noise levels from equation (2).

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TABLE I

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

D	=	8	feet	,

	1,,													So	und-p	ressu	re le	evel,	db										
В.	Mt	F	reque	ency, c	:ps	I	I ₂	13	I4	I	I ₂	13	Ių	ıı	I ₂	13	I4	Iı	I ₂	13	14	Iı	I ₂	13	14	Iı	I ₂	13	I4
		fl	f ₂	f ₃	f ₄	2	P _H =	1000		1	P _H = 2000				P _H =	4000			P _H =	6000			PH =	8000		P	H =]	10,000)
3	0.4 .5 .6 .7 .8 .9	67 81 94 107	107 134 161 188 215 242 269	161 202 242 283 322 363 403	215 269 323 377 430 484 538	94 96 100 103 106 109 111	74 83 81 97 103 107 111	51 68 79 89 95 105 110	24 50 67 80 92 101 108	100 102 106 108 112 114 117	79 88 96 103 108 112 116	57 73 85 95 100 110	29 56 73 86 97 106 114	106 108 111 114 117 120 122	85 94 102 108 114 118 122	63 78 90 100 105 115 121	35 62 78 91 103 112 119	109 111 115 117 120 123 125	89 98 105 112 117 121 125	66 82 93 103 109 119 124	39 65 82 95 106 115 122	112 114 117 120 123 125 127	91 100 108 114 119 123 127	69 85 96 106 111 121 126	41 67 84 97 108 117 124	113 115 119 121 124 127 129	93 102 110 116 121 125 129	71 86 98 108 113 123 128	43 69 86 99 110 119 126
1	0.4 .5 .6 .7 .8 .9	72 90 108 126 143 162 179	143 179 215 251 286 322 358	215 269 323 377 430 484 538	286 358 430 502 573 645 717	85 91 97 101 106 107 111	42 57 83 91 100 105 110	24 50 67 80 92 101 108	28 50 69 83 96 106	91 96 102 107 111 112 116	47 62 89 97 105 110 116	29 56 73 86 97 106 114	5 33 56 7 5 88 101 111	97 102 108 112 116 117 121	53 68 95 102 111 116 121	35 61 78 91 103 112 119	11 39 61 80 94 106 116	100 105 111 116 120 120 124	57 71 98 105 114 119 124	39 65 82 95 106 115 122	14 42 64 84 97 110	103 108 114 118 122 123 127	59 74 100 108 116 121 126	41 67 84 97 108 117 124	17 45 67 86 99 112 122	105 110 116 120 124 124 128	61 76 102 110 118 123 128	43 69 86 99 110 119 126	19 47 69 88 101 114 123
6	0.4 .5 .6 .7 .8 .9	107 134 161 188 215 242 269	215 269 323 377 430 484 538	322 403 484 565 644 725 806	430 538 646 754 859 967 1075	74 83 91 97 103 107 111	24 50 67 80 92 101 108	17 41 63 79 93 104	8 28 65 85 100	79 88 96 103 108 112 116	29 56 73 86 97 106 114	22 47 68 85 98 110	13 33 70 90 105	86 94 102 108 114 118 122	35 62 78 91 103 112 119	28 52 74 90 104 115	19 38 76 96 110	89 98 105 112 117 121 125	39 65 82 95 106 115 122	32 56 77 93 107 118	 22 42 79 99 114	91 100 108 114 119 123 127	41 67 84 97 108 117 124	33 58 80 95 109 120	25 44 82 101 116	93 102 110 116 121 125 129	43 69 86 99 110 119 126	36 60 82 97 111 122	27 46 84 103 118
8	0.4 .5 .6 .7 .8 .9	143 179 215 251 286 322 358	286 358 430 502 573 645 717	430 538 646 754 859 967 1075	573 717 861 1005 1145 1290 1434	59 72 83 91 100 105 110	28 50 69 83 96 106	8 28 65 85 100	18 48 73 93	64 78 89 97 105 110	5 33 56 75 88 101 111	13 33 70 90 105	 24 53 78 99	70 83 95 102 111 116 121	11 39 62 80 94 106 116	 19 38 76 96 110	 29 58 84 104	74 87 98 105 114 119	14 45 65 84 97 110	22 42 79 99 114	 32 62 87 107	76 89 100 108 116 121 126	17 45 67 86 100 112	25 44 82 101 116	35 64 89 109	78 91 102 110 118 123 128	19 47 69 88 101 114 123	27 46 84 103 118	36 66 91 111

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TABLE I .- Continued

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

D = 12 feet

	Π													Č.	Sound-	-pres	sure	level	, db										
В	Mt	Fr	-e quer	ncy,	ps	I	I ₂	1,3	I ₁	Il	I ₂	13	14	Il	I ₂	I ₃	14	Il	I ₂	I3	14	Il	I ₂	13	I _l	Il	I ₂	13	14
		fl	f2	f ₃	fl		P _H =	1000			PH =	H = 2000			PH =	4000		P	H =	6000		F	H =	8000		F	Н =	10,00	0
3	0.4 .5 .6 .7 .8 .9	36 45 54 63 72 81 90	72 90 108 125 143 161 179	108 134 161 188 215 242 269	143 179 215 251 287 323 358	91 94 97 100 103 107 109	70 80 88 95 101 105 109	48 65 76 86 92 102 108	20 47 64 78 89 99 106	97 99 103 106 109 112 114	76 85 93 100 106 110	54 70 82 92 97 107 113	26 53 70 83 95 104 111	102 105 108 111 114 117 119	82 91 99 105 111 115 119	60 76 87 97 103 113 118	32 58 75 88 100 109 116	106 108 111 114 117 120 122	85 94 102 109 114 118 122	63 79 90 100 106 116 121	35 62 79 92 103 112 119	108 111 114 117 120 122 124	88 97 105 111 116 121 124	66 82 93 103 108 118 123	38 64 81 94 105 114 122	110 113 116 118 121 124 126	90 99 106 113 118 122 126	67 83 95 105 110 120 125	39 66 83 96 107 116 123
4	0.4 .5 .6 .7 .8 .9	48 60 72 84 96 108 119	96 119 143 167 191 215 239	143 179 215 251 287 323 358	191 239 288 335 382 430 478	82 88 94 99 103 104 109	38 54 80 88 97 103 108	20 47 64 77 89 99 106	25 47 67 90 93 104	88 93 100 104 108 109 114	44 59 86 94 102 108 113	26 53 70 83 96 104 111	 30 53 72 86 98 109	93 99 105 110 113 114 119	50 65 91 99 108 113 119	32 58 75 88 100 109 116	8 36 58 77 91 104 114	97 102 108 113 117 118 122	53 68 95 103 111 116 121	35 67 78 92 103 111 120	11 39 62 81 94 107 117	99 105 111 115 119 120 124	56 71 97 105 113 119 124	38 64 81 94 105 114 122	13 42 64 83 96 109 119	101 106 113 117 121 122 126	58 74 99 107 115 120 125	39 66 83 96 107 117 123	15 43 66 85 98 111 121
6	0.4 .5 .6 .7 .8 .9	72 90 108 125 143 161 179	143 179 215 251 287 323 358	215 269 323 376 430 484 538	287 358 430 502 573 645 717	70 80 88 95 101 105 109	20 47 64 78 89 99 1 0 6	14 39 60 77 91 102	5 25 63 83 98	76 85 93 100 106 110	26 53 70 83 95 104 111	19 43 66 82 96 107	11 30 68 88 103	82 91 99 105 111 115 119	32 58 75 88 100 109 116	25 49 71 87 101 112	16 35 73 93 108	85 94 102 109 114 118 122	35 62 79 92 104 112 120	 28 52 74 90 104 116	 19 39 76 96 111	88 97 105 111 116 121 124	38 64 81 94 105 114 122	31 55 77 92 106 118	 22 41 78 98 113	90 98 106 113 118 123 126	40 66 83 96 107 116 124	32 57 78 94 108 119	 24 43 80 100 115
8	0.4 .5 .6 .7 .8 .9	96 119 143 167 191 215 239	191 239 287 335 382 430 478	287 358 430 502 573 645 717	382 478 573 669 764 860 956	55 69 80 88 97 103 108	25 48 67 80 93 104	5 25 63 83 98	 15 45 70 91	61 74 86 94 102 108 113	30 53 72 86 98 108	 11 30 68 88 103	 21 50 76 96	67 80 91 99 108 113 119	8 36 58 77 91 104 114	16 35 73 93 108	 26 55 81 101	70 84 95 103 111 116 122	11 39 62 87 94 107 117	 19 39 76 96 111	 29 59 84 105	73 86 97 105 113 119 124	13 42 64 83 96 109 119	 22 41 78 98 113	 32 61 86 107	75 88 99 107 115 120 125	16 43 66 85 98 111 121	24 43 80 100 115	 33 63 88 108

TABLE I.- Continued

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

D = 16 feet

В	B M _t Frequency, cps				cps									5	Sound-	press	ure 1	Level,	db											
					.,		I	I ₂	13	Ių	Il	I ₂	13	14	Iı	I ₂	I ₃	1)4	I	I ₂	I3	14	I	I ₂	13	I ₄	Iı	I ₂	I3	I _{l4}
			fl	f ₂	f3	f) ₄		P _H = :	1000			P _H =	2000			P _H =	4000			P _H =	6000			P _H =	8000			PH =	10,00	00
3	0.1	5 6 7 8 9	27 34 40 47 54 60 67	54 67 80 94 108 121 134	81 101 121 141 161 181 202	108 134 161 188 215 242 269	89 92 95 98 102 104 108	68 78 86 93 99 103 108	46 67 74 85 90 101 107	22 45 62 76 88 97 105	94 97 101 104 107 110	74 83 91 98 104 108 112	52 67 79 90 95 106 111	24 51 68 81 93 102 110	100 103 106 109 112 115 117	80 89 97 103 109 113 117	58 73 85 95 101 112 116	30 56 73 86 98 107 114	103 106 109 112 115 118 120	83 92 100 107 111 116 120	61 76 88 98 104 113 119	33 59 77 90 101 110 118	106 109 112 114 118 121 123	85 94 102 109 114 119 123	63 78 91 101 106 116 122	36 62 79 92 103 112 120	108 110 114 116 119 122 124	87 96 104 111 116 120 124	65 80 92 102 108 118 123	37 64 81 93 105 114 121
4	0.1	5 7 8	63 72 81	72 90 108 125 143 161 179	108 134 161 188 215 242 269	143 179 215 251 287 323 358	80 86 92 97 101 103 107	36 51 78 86 95 101 107	18 45 62 76 88 97 105	22 46 65 79 92 102	86 91 97 102 106 108 112	42 57 84 92 101 106 112	24 51 68 81 93 102 110	28 51 70 84 97 107	91 97 103 108 112 113	48 63 89 97 106 111 117	30 56 73 86 98 107 115	34 56 75 89 102 112	95 100 106 111 115 116 120	51 66 93 100 109 114 120	33 59 76 90 101 110 118	37 60 78 92 105	97 102 108 113 117 118 122	53 68 95 103 111 117 122	36 62 79 92 103 112 120	40 62 81 94 107	99 104 110 115 119 120 124	55 70 97 104 113 117 124	37 64 81 93 105 114 122	42 64 82 96 109 119
6	0.4 •5 •6 •7 •8 •9	3 10	67 81 94 08 21	108 134 161 188 215 242 269	161 202 242 282 323 363 403	215 269 323 376 430 484 538	68 78 86 93 98 103 108	18 45 62 76 88 97 105	12 36 58 75 89 101	23 61 81 96	74 83 91 98 104 108 112	24 51 68 81 93 102 110	16 42 64 80 94 106	 28 66 86 101	80 89 97 103 109 113 117	30 56 73 86 98 107 115	22 47 69 85 100 111	 14 33 71 91 106	83 92 100 107 111 116 120	33 59 77 90 101 110 118	25 50 72 88 102 114	17 37 74 94 109	85 94 102 109 114 119 123	36 62 79 92 103 112 120	28 53 74 90 104 116	19 39 77 96 111	87 96 104 111 116 120 124	38 64 81 93 105 119 121	30 54 76 92 106 117	21 41 78 98 113
8	0.4 .5 .6 .7 .8 .9	9	90 08 25 43 61	143 179 215 251 287 323 358	215 269 323 376 430 484 538	287 358 430 502 573 645 717	53 67 78 86 95 101 107	22 46 65 78 92 102	 4 23 61 81 96	 14 43 69 90	59 72 84 92 101 106 112	28 51 70 84 97 107	8 28 66 86 101	19 48 74 95	64 78 89 97 106 111	5 34 56 75 89 102 112	14 33 71 91 106	 24 54 79 100	68 81 93 100 109 114 120	9 37 60 78 92 105 115	17 37 74 94 109	27 57 82 103	70 84 95 103 111 117 122	11 40 62 81 94 107 117	 19 39 77 96 111	30 59 84 105	72 86 97 104 113 117 124	13 42 64 82 96 109 119	 21 41 78 98 113	 31 61 86 106

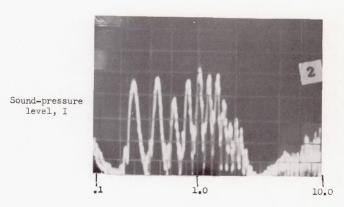
TABLE I.- Concluded

CALCULATED SOUND-PRESSURE LEVELS OF THE FIRST FOUR ROTATIONAL-NOISE

HARMONICS FOR VARIOUS PROPELLER OPERATING CONDITIONS

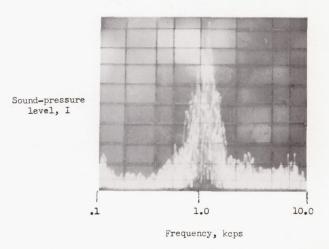
D = 20 feet

В	M.	F*	COURT	ncy,	ng										Sound	-pres	sure	level	., db										
D	^M t	11	equei	rcy, (5 p3	Il	I ₂	I ₃	Il	I	I ₂	13	14	Iı	I ₂	13	I ₄	I	I ₂	13	14	Il	I ₂	13	14	I ₁	I ₂	I ₃	Ių
		fl	f ₂	f3	Ŋ		P _H =	1000			P _H =	2000			P _H =	4000			P _H =	6000			P _H =	8000			P _H =	10,00	00
3	0.4 .5 .6 .7 .8 .9	22 27 32 38 43 48 54	43 54 64 75 86 97 108	65 81 97 113 129 145 161	86 108 129 150 172 194 215	87 90 94 97 101 104 106	67 76 85 91 97 102 106	42 60 73 83 89 99 105	17 44 61 74 86 96 104	92 96 100 102 106 109 111	72 82 90 97 102 107 111	50 65 78 88 94 104 110	22 49 66 73 91 95 108	98 101 104 108 111 114 116	78 87 95 102 108 112 116	56 71 84 94 99 109 115	28 55 72 85 96 106 113	102 104 108 111 114 117 119	81 90 98 105 111 115 119	59 74 86 97 102 112 118	31 58 75 88 100 109 116	104 107 110 113 116 119 121	84 93 101 107 113 117 121	62 76 89 100 104 115 120	34 60 77 90 102 111 118	106 109 112 115 118 121 123	85 95 103 109 115 119 123	64 78 91 101 106 116 122	36 62 79 92 103 113 120
4	.4 .5 .6 .7 .8 .9	29 36 43 50 57 65 72	57 72 86 100 115 129 143	86 108 129 150 172 194 215	115 143 172 201 229 258 287	78 84 91 96 100 101 106	35 50 77 85 94 100 106	43 61 74 86 96 104	21 44 64 77 90 101	84 89 96 101 105 106 111	40 55 82 90 99 105 111	22 49 66 79 91 101 108	27 49 69 82 95 106	89 95 101 106 110 111 116	46 61 88 96 104 110 116	28 55 72 85 96 106 113	32 55 74 88 100	93 98 104 109 113 114 119	49 64 91 99 107 113 118	31 58 75 88 99 109 116	7 36 58 77 91 103 114	95 100 107 111 115 116 121	52 66 93 101 110 115 120	13 60 78 90 102 111 118	10 38 60 79 93 106 116	97 102 109 113 117 118 122	55 68 95 103 111 117 122	35 62 79 92 103 113 120	11 40 62 81 95 108 117
6	0.4	43 54 64 75 86 97 108	86 108 129 150 172 194 215	129 161 193 226 258 290 323	172 215 258 301 344 387 430	66 76 85 91 97 102 106	17 43 61 74 86 96 104	10 35 57 73 88 100	 4 22 60 80 95	72 82 90 96 102 107 111	22 49 66 78 85 100 108	15 40 62 68 93 104	 7 27 32 85 94	78 87 95 102 108 112 116	28 55 72 85 96 106 113	21 45 68 83 98 109	12 32 64 90 105	81 90 98 105 111 115 119	31 58 75 88 100 109 116	24 49 70 87 101	16 35 73 93 108	84 93 101 107 113 117 121	33 60 77 90 102 111 118	27 51 73 89 103 114	18 37 75 94 110	85 95 103 109 115 119 123	35 62 79 92 103 113 120	28 53 75 91 105 116	 20 39 77 97 111
8	0.4 .5 .6 .7 .8 .9	57 72 86 100 115 129 143	115 143 172 200 229 258 287	172 215 258 301 344 387 430	229 287 344 401 459 516 573	51 65 77 85 94 100 106	 21 44 64 77 90 101	 4 22 60 80 95	12 12 12 68 89	57 71 82 90 99 105	27 49 49 82 95 106	7 27 65 85 99	 17 47 73 93	63 76 88 96 104 110 116	5 32 55 74 88 100 111	 12 32 70 90 105	 22 52 58 98	66 79 91 99 107 113 118	7 15 58 77 91 103 114	16 35 73 92 108	 26 55 81 101	69 82 93 101 110 115 120	9 37 60 79 93 106 116	18 37 75 95 110	28 57 83 103	70 84 95 103 111 117 122	11 40 62 81 94 107 117	 20 39 77 97 111	 30 59 85 105

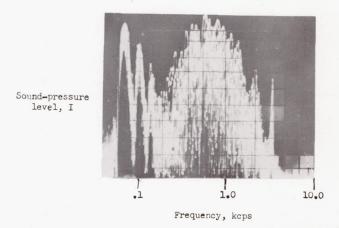


Frequency, kcps

(a) Rotational noise from high-speed propeller.



(b) Vortex noise from rotating rods.



(c) Composite spectrum of rotational and vortex noise.

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Figure 1.- Spectrums of components of propeller noise.

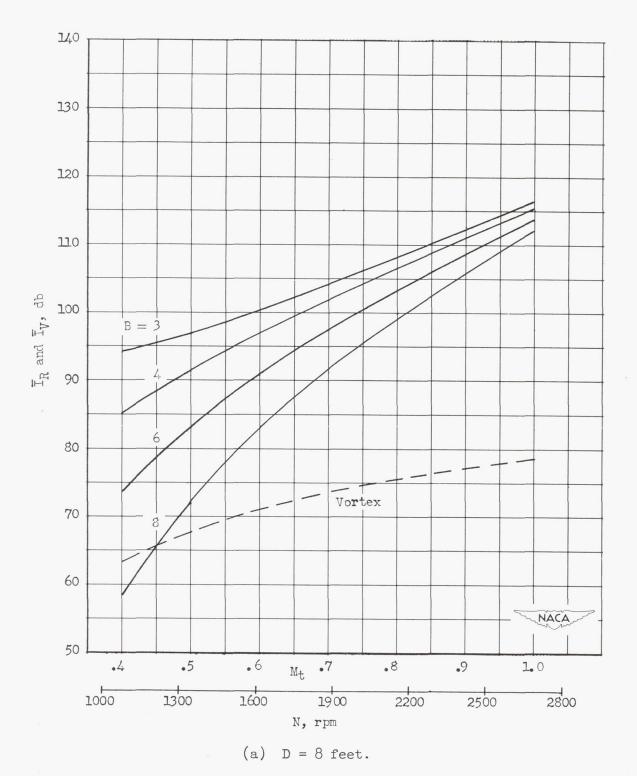
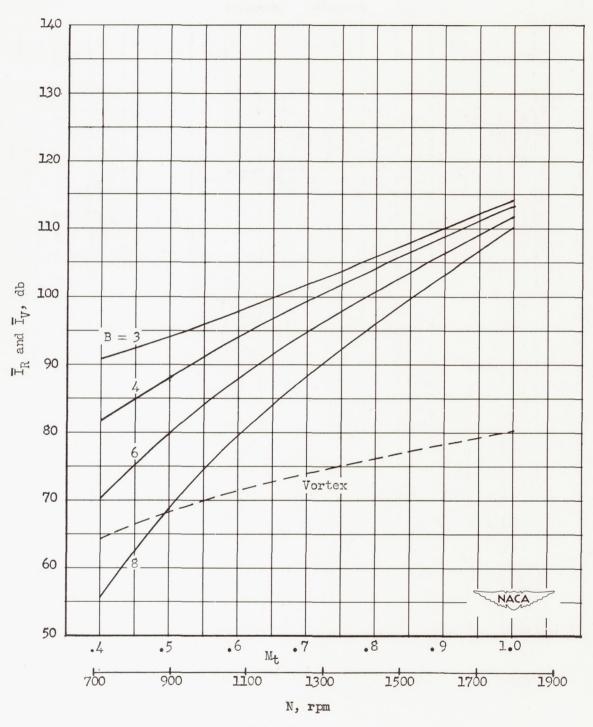
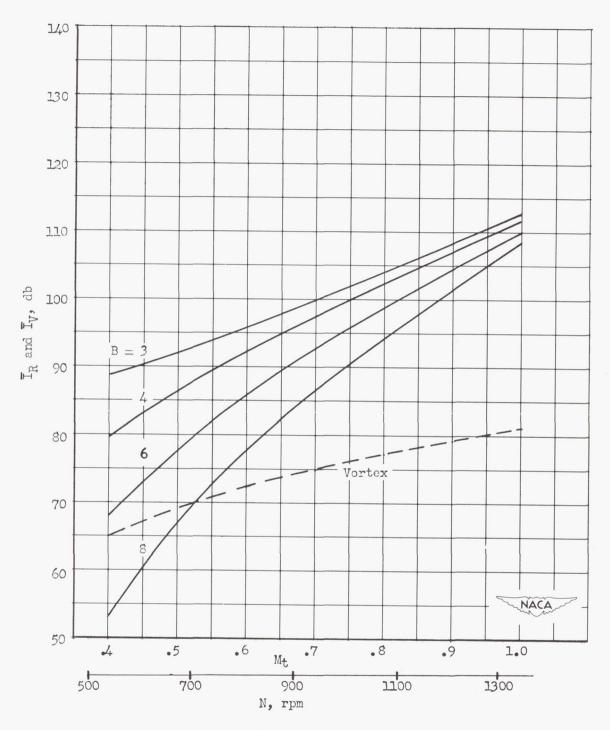


Figure 2.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. $P_{\rm H}$ = 1,000 horsepower; s = 300 feet.



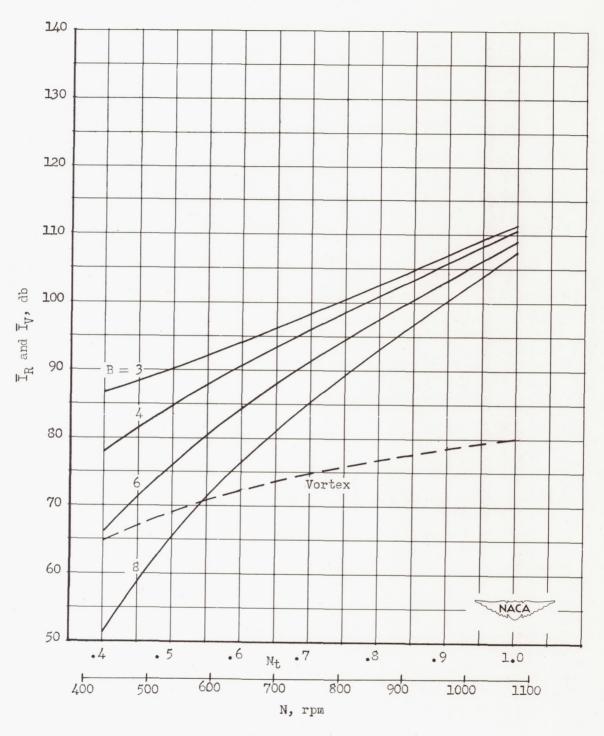
(b) D = 12 feet.

Figure 2.- Continued.



(c) D = 16 feet.

Figure 2.- Continued.



(d) D = 20 feet.

Figure 2.- Concluded.

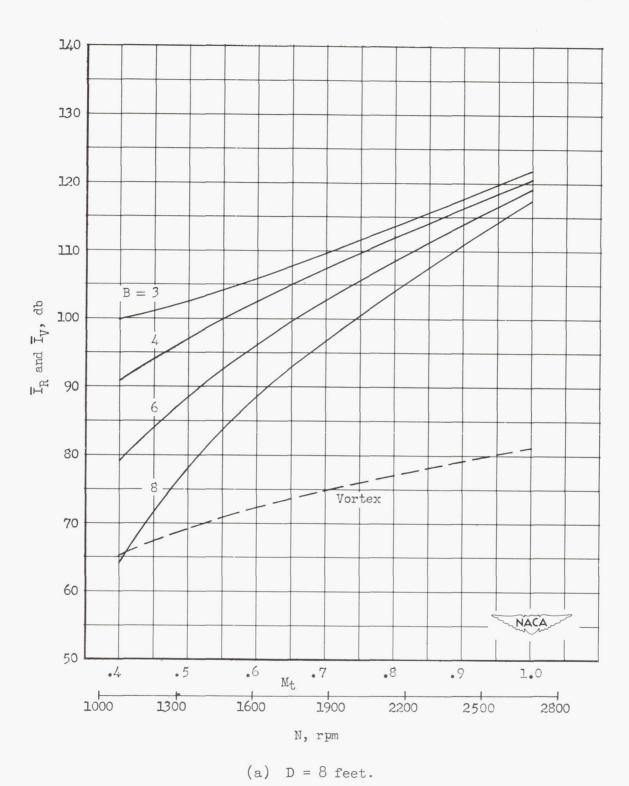
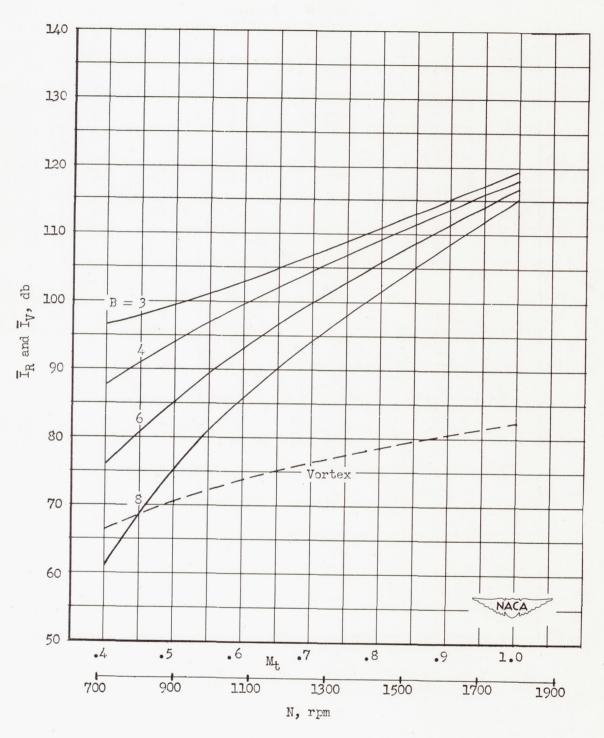
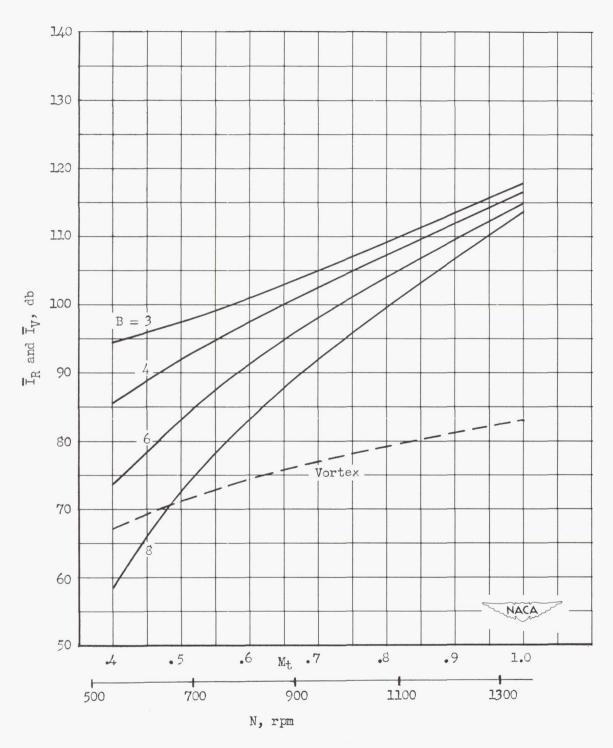


Figure 3.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. $P_{\rm H}$ = 2,000 horsepower; s = 300 feet.



(b) D = 12 feet.

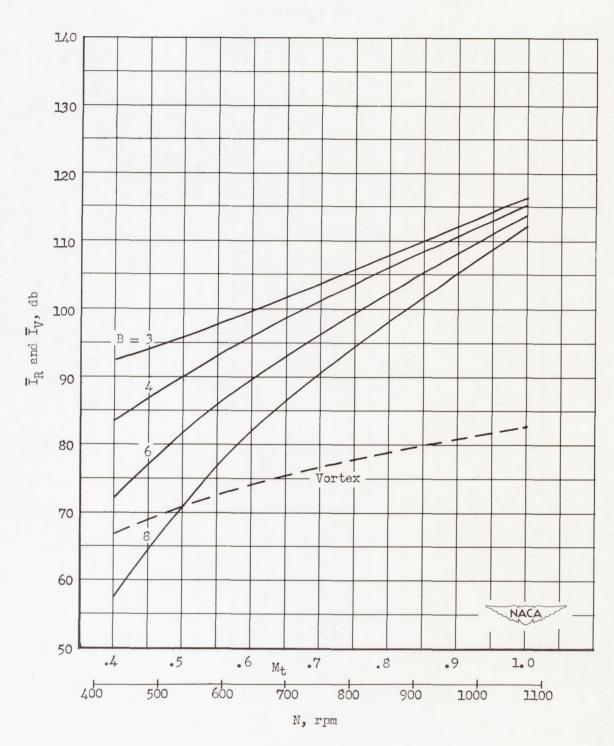
Figure 3.- Continued.



(c) D = 16 feet.

Figure 3.- Continued.

Y



(d) D = 20 feet.

Figure 3.- Concluded.

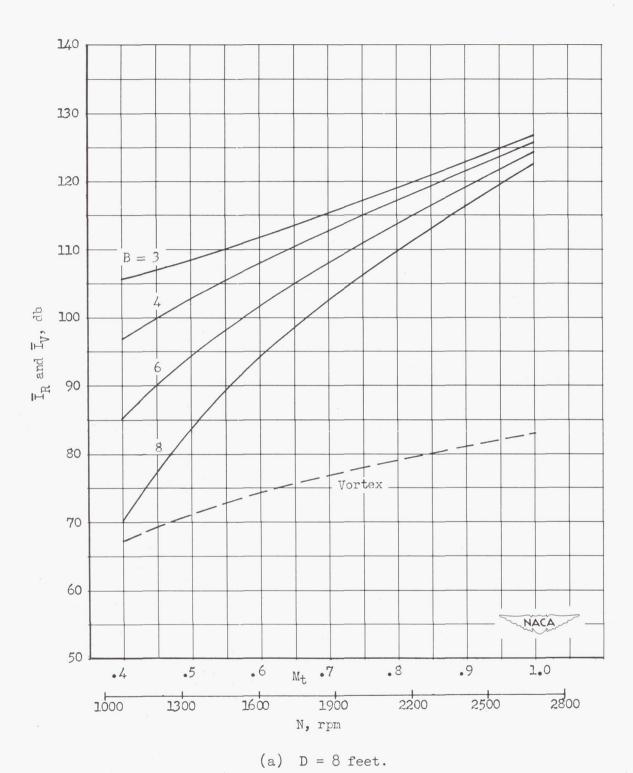
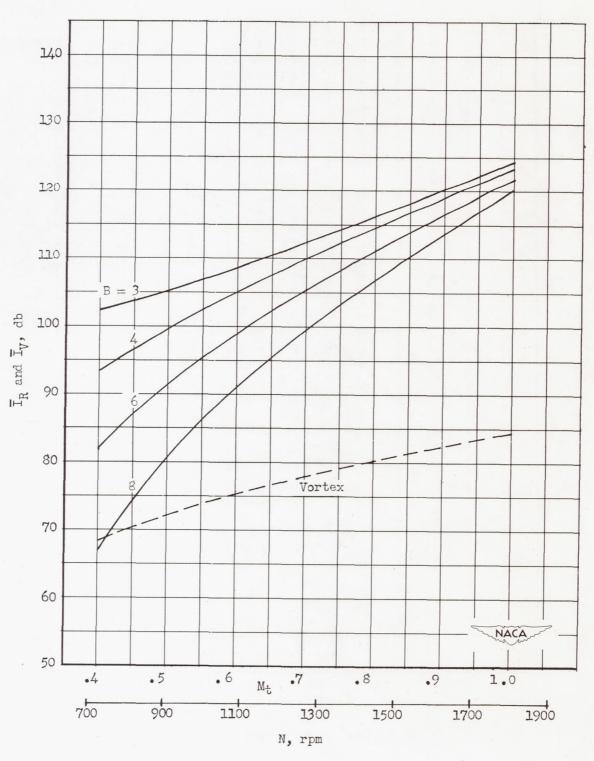
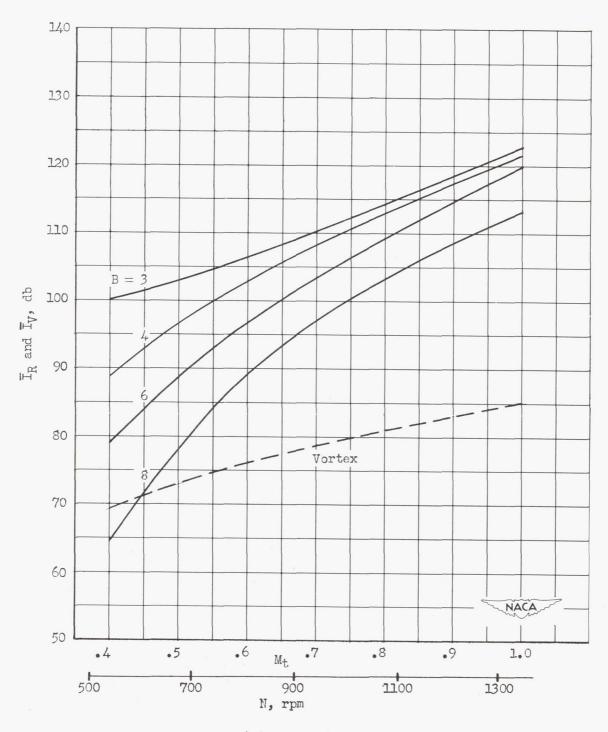


Figure 4.- Propeller sound-pressue levels as functions of tip Mach number and rotational speed for various numbers of blades. $P_{\rm H}$ = 4,000 horsepower; s = 300 feet.



(b) D = 12 feet.

Figure 4.- Continued.



(c) D = 16 feet.

Figure 4.- Continued.

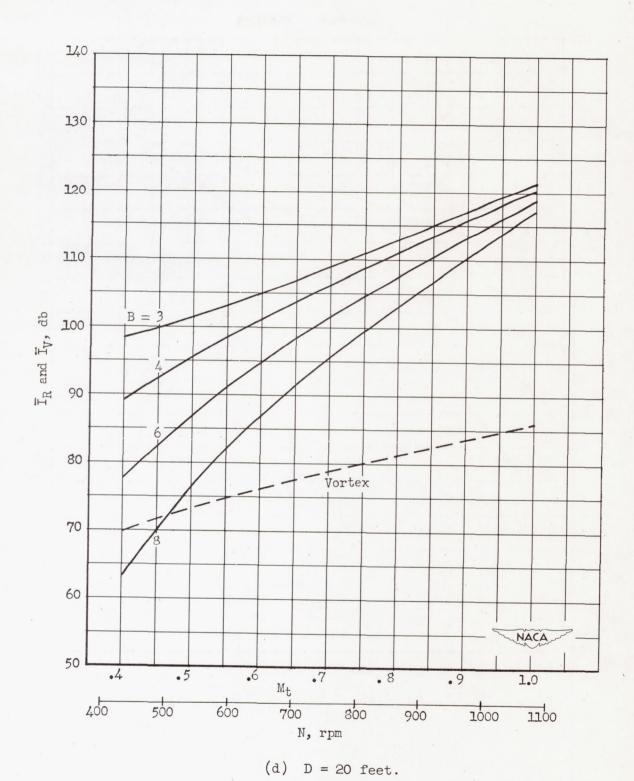


Figure 4.- Concluded.

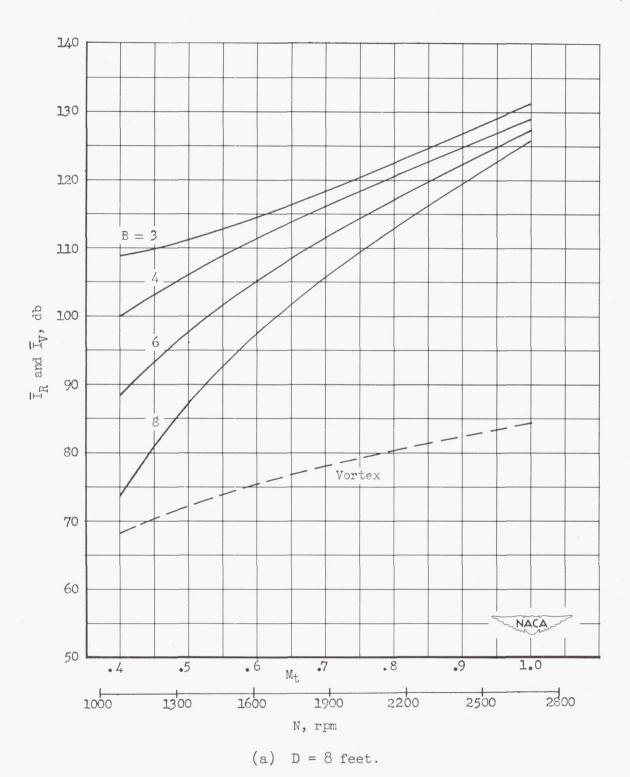
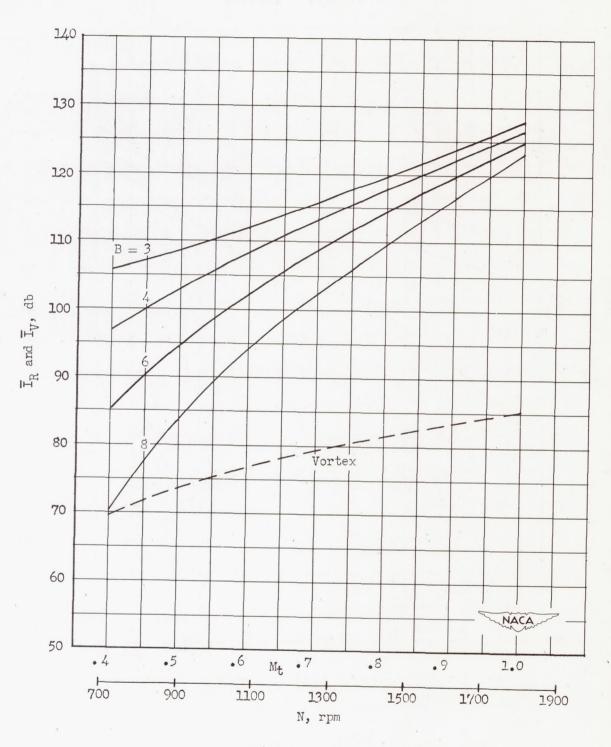
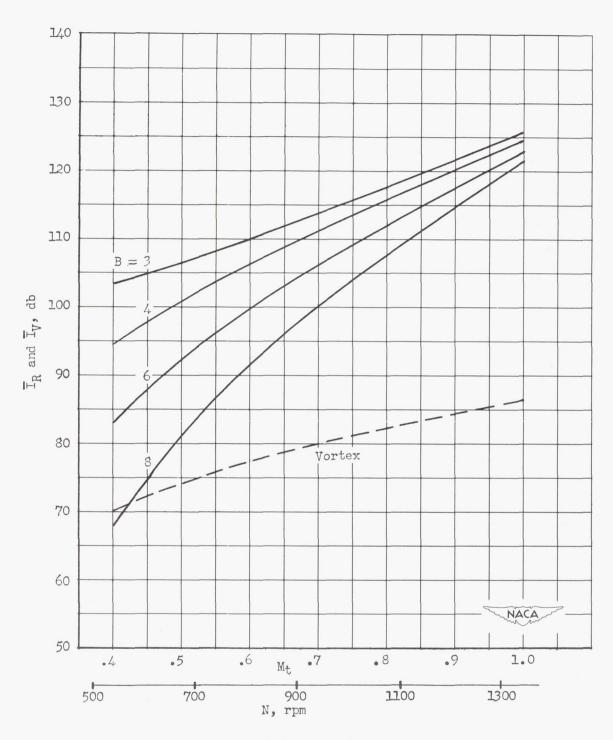


Figure 5.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. $P_{\rm H}$ = 6,000 horsepower; s = 300 feet.



(b) D = 12 feet.

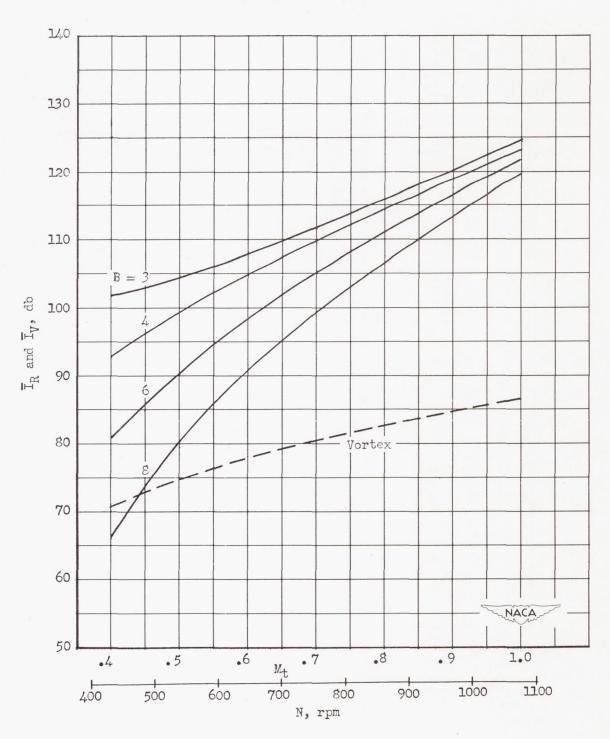
Figure 5.- Continued.



(c) D = 16 feet.

Figure 5.- Continued.





(d) D = 20 feet.

Figure 5.- Concluded.

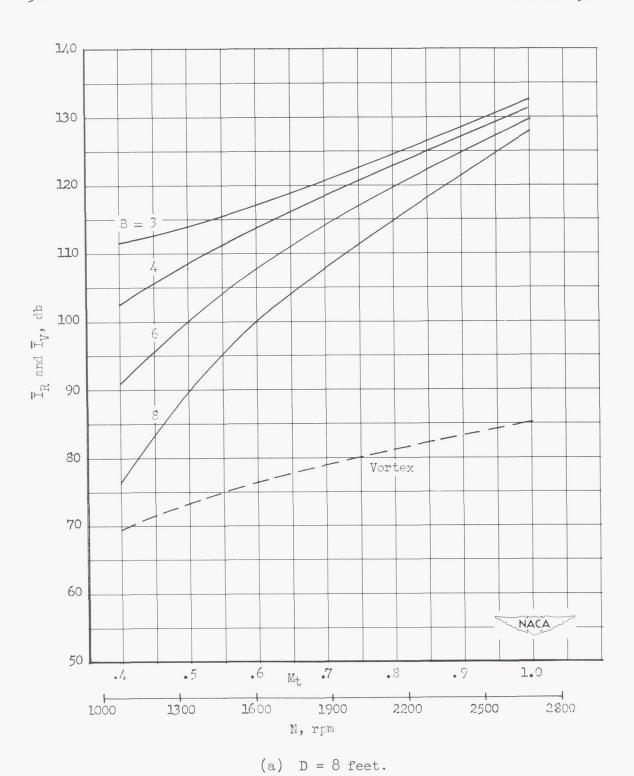
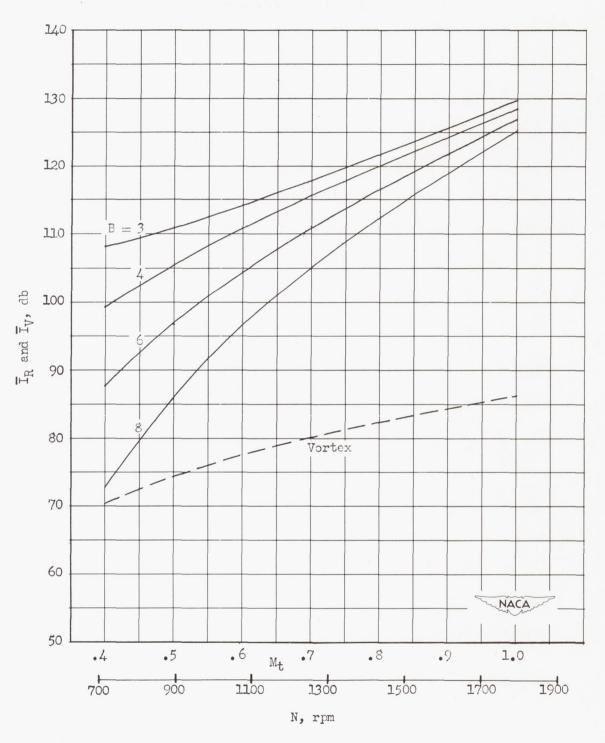
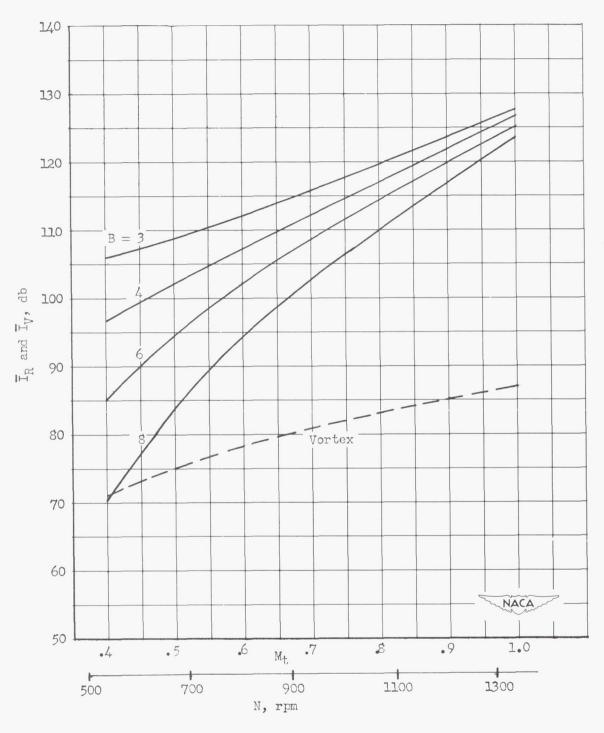


Figure 6.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. $P_{\rm H}$ = 8,000 horsepower; s = 300 feet.



(b) D = 12 feet.

Figure 6.- Continued.



(c) D = 16 feet.

Figure 6.- Continued.

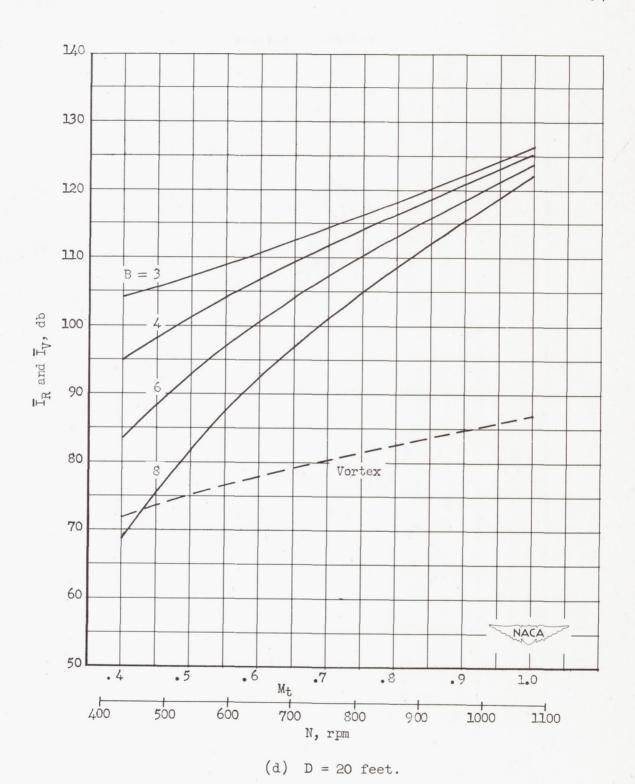


Figure 6.- Concluded.

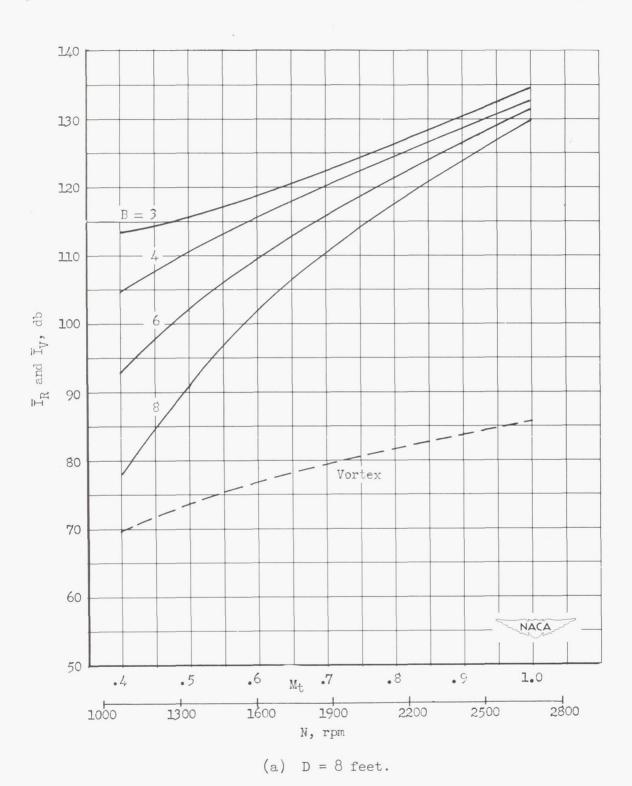
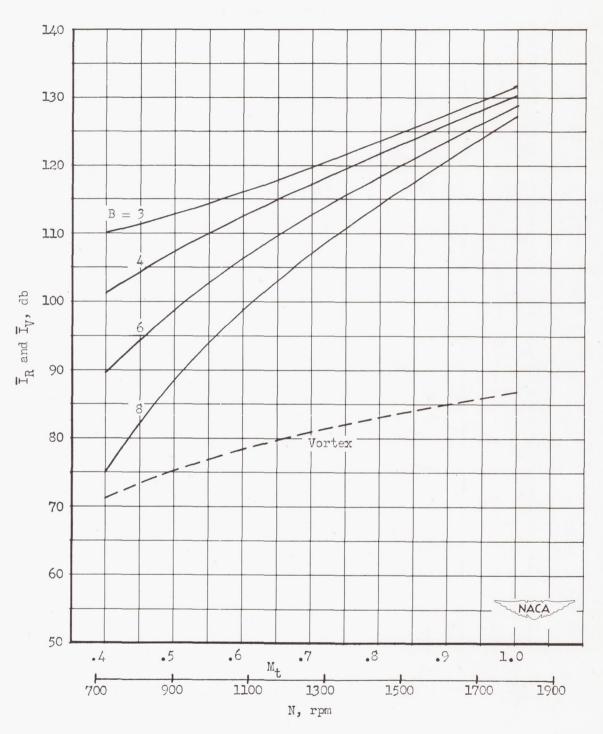
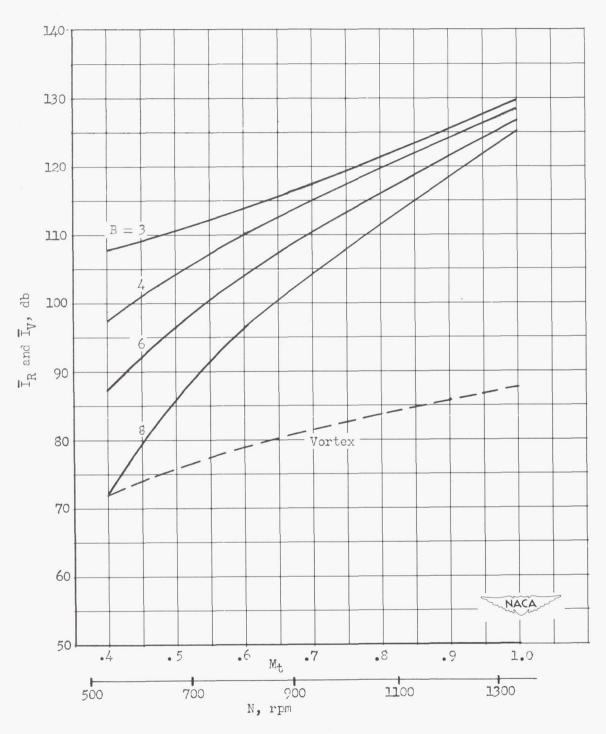


Figure 7.- Propeller sound-pressure levels as functions of tip Mach number and rotational speed for various numbers of blades. $P_{\rm H}$ = 10,000 horsepower; s = 300 feet.



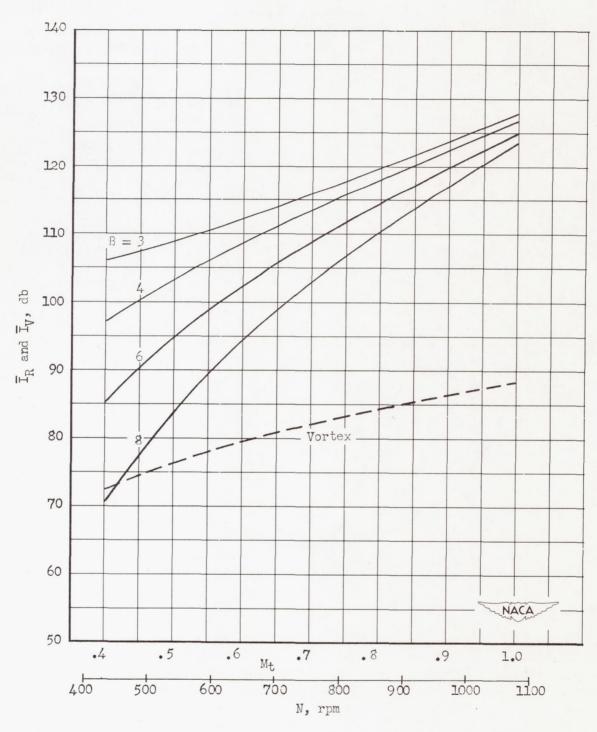
(b) D = 12 feet.

Figure 7.- Continued.



(c) D = 16 feet.

Figure 7.- Continued.



(d) D = 20 feet.

Figure 7.- Concluded.

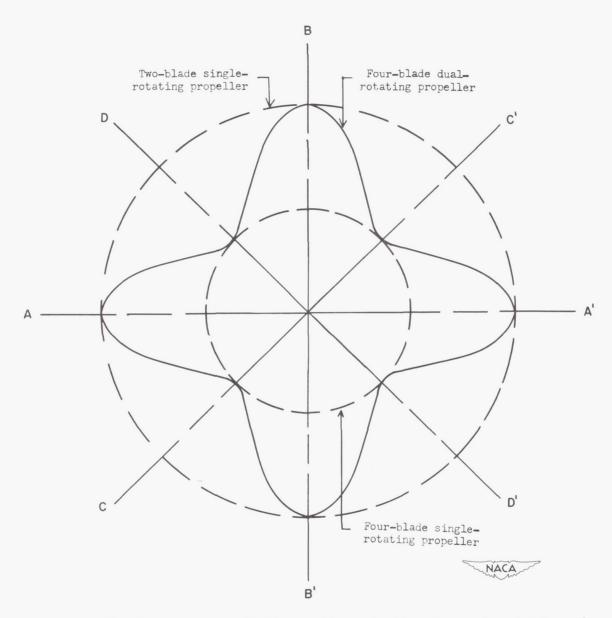


Figure 8.- Free-space radiation pattern in the plane of rotation of three different propellers at the same power and tip Mach number.

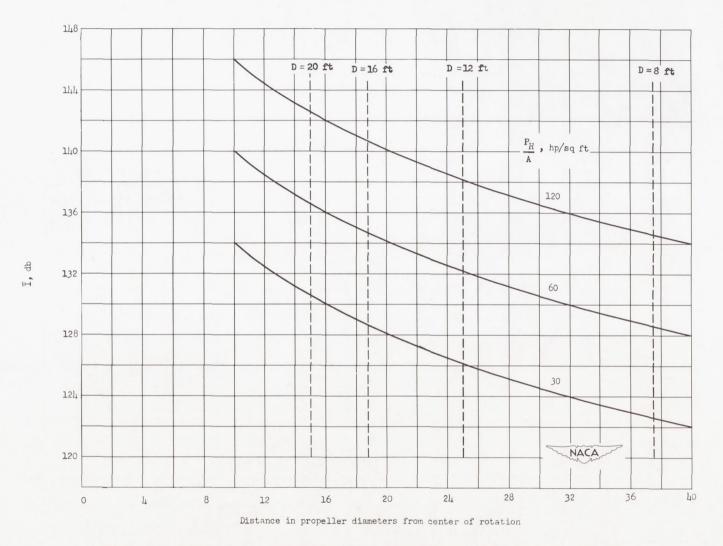


Figure 9.- Chart for estimating the over-all noise from supersonictype propellers. (Dashed lines indicate distances of 300 feet for four different values of propeller diameter.)

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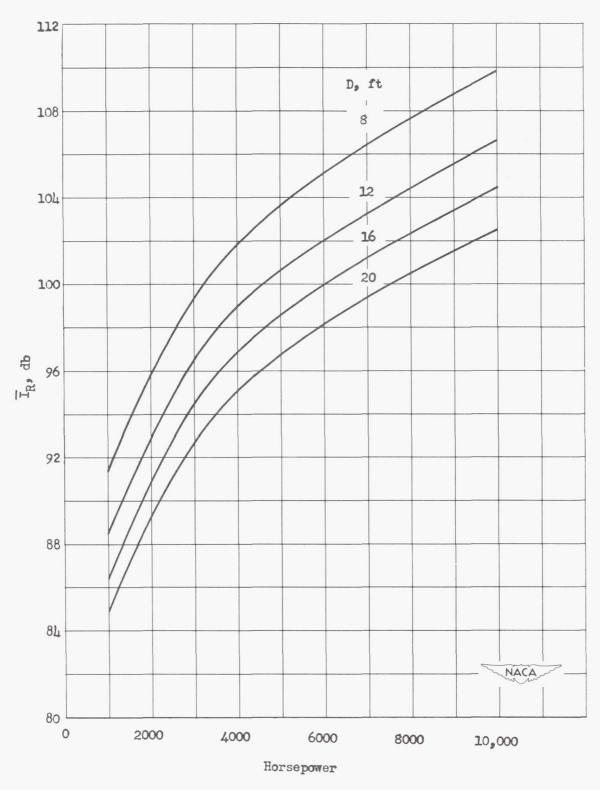


Figure 10.- Sound-pressure level of propeller rotational noise as a function of power input and diameter. B = 6; M_{t} = 0.6; s = 300 feet.

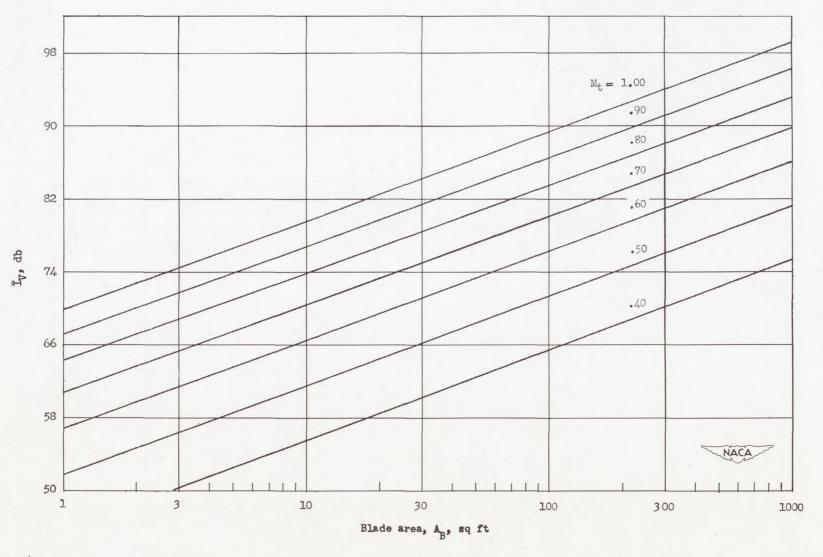


Figure 11.- Sound-pressure levels of vortex noise as a function of propeller-blade area and tip Mach number.

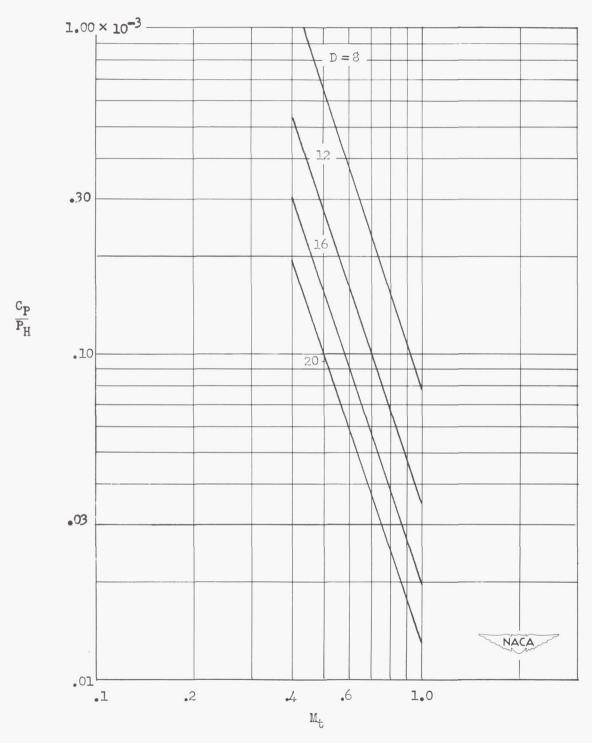


Figure 12.- Power coefficient per unit horsepower as a function of tip Mach number and propeller diameter. ρ = 0.002378 slugs per cubic foot.

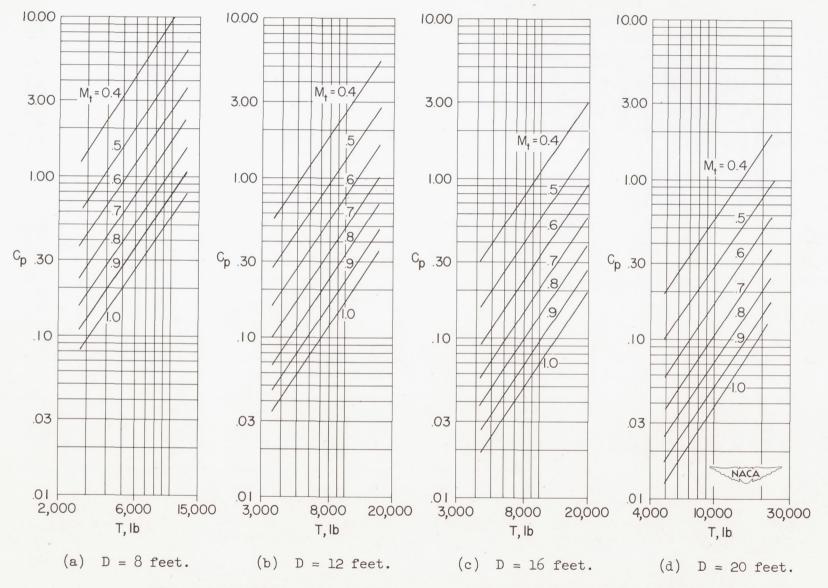


Figure 13.- Static thrust for a given power coefficient as a function of tip Mach number and propeller diameter.